EXPERIMENTAL STUDY OF THREE-NUCLEON DYNAMICS IN PROTON–DEUTERON BREAKUP REACTION*

A. Rusnok[a], I. Ciepał[b], B. Jamróz[a], N. Kalantar-Nayestanaki[c] G. Khatri[d], St. Kistryn[d], B. Kłos[a], A. Kozela[b], J. Kuboś[e] P. Kulessa[b], A. Liptak[e], W. Parol[b], I. Skwira-Chalot[f] E. Stephan[a], A. Wilczek[a], B. Włoch[b], J. Zejma[d]

[a]Institute of Physics, University of Silesia, Katowice, Poland
[b]The H. Niewodniczański Insitute of Nuclear Physics, PAN, Kraków, Poland
[c]KVI-CART, University of Groningen, Groningen, The Netherlands
[d]The M. Smoluchowski Inst. of Physics, Jagiellonian University, Kraków, Poland
[e]Faculty of Physics and Applied Computer Science
AGH University of Science and Technology, Kraków, Poland
[f]Faculty of Physics, University of Warsaw, Warszawa, Poland

(Received December 14, 2016)

A measurement of the differential cross sections for the proton–deuteron elastic scattering and the deuteron breakup in collision with a proton was carried out at Cyclotron Center Bronowice using the BINA detection system. The very preliminary analysis of the experimental data taken at three proton beam energies: 108, 135 and 160 MeV is presented.

DOI:10.5506/APhysPolB.48.485

1. Motivation

Research in the domain of few-nucleon systems is the basis for understanding of nuclear interactions and properties of nuclei. The proton–deuteron breakup reaction can serve as a tool for testing modern approaches to describe nuclear interactions between three nucleons [1–3]. At intermediate energies, below the threshold for pion production, a comparison of the data with exact theoretical calculations is possible and effects of the dynamics beyond the pairwise nucleon–nucleon interaction, the so-called three-nucleon force (3NF), are significant. Beside the 3NF, the Coulomb interaction and relativistic effects also affect the differential cross section of the breakup reaction.

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 28–September 4, 2016.

A series of experiments was carried out at KVI Groningen and FZ-Jülich to determine cross section and polarization observables of the $^1\mathrm{H}(d,pp)n$ and $^2\mathrm{H}(p,pp)n$ breakup reactions at intermediate energies [4–10]. The experimental data confirmed importance of the 3NF and huge influence of the Coulomb interaction between protons at certain kinematic configurations. There are also regions and observables where *pd* elastic scattering and/or breakup reaction data are not well-described by the state-of-the-art theoretical calculations. The database for the breakup reaction is still limited in studied energies, which hinders the conclusions on the role of 3NF and on the deficiencies of the description given by the current models. As a continuation of the studies, the measurements are carried out at the new Cyclotron Center Bronowice (CCB, Kraków), at three proton beam energies (108, 135, 160 MeV).

The combination of large phase space coverage of the BINA detector system and wide range of accessible beam energies provides a unique possibility to study various aspects of the dynamics in the three-nucleon system, in regions of their maximum visibility.

2. Experiment and preliminary results

The BINA detection system is defined by a large angular acceptance and low-energy threshold for the particle detection [11, 12]. It is composed of two detector groups — Wall and Ball. The Wall, covering the forward scattering angles (12°–35° in the lab-frame), consists of a multiwire proportional chamber (MWPC) and scintillation hodoscope system ΔE–E. MWPC provides information for exact reconstruction of the momentum direction of the charged particles, whereas the ΔE–E system is applied for charged particle identification and total energy measurement. The backward angles (35°–160° in the lab-frame) are covered by the second detector group, Ball, consisting of 149 "phoswich"-type scintillation detectors dedicated to measurement of the particle energy and to approximate determination of the momentum direction. The liquid D_2 target is located inside the Ball detector which serves also as a vacuum chamber.

The first data have been collected for elastic scattering and the *pd* breakup reaction at three proton beam energies: 108, 135 and 160 MeV. The Ball part was not fully operational at the time of the measurements, so the preliminary analysis is devoted to checking consistency of the data collected in the Wall part. The high efficiency of MWPC has been demonstrated. A sample particle identification spectrum, obtained for one "virtual telescope", *i.e.* the combination of overlapping elements of the ΔE and E detectors, is presented in Fig. 1 (left panel). Proton and deuteron bands and spots are well-visible allowing for clear definition of corresponding graphical cuts. The simplified energy calibration has been applied leading to a proper distribution of proton–proton coincidences along the corresponding three-body breakup reaction kinematics (see Fig. 1 (right panel)). The clean spectrum below the breakup kinematics proves low level of accidental coincidences. The number of events collected at beam energy of 108 MeV corresponds to an average statistical accuracy of about 4–5% in one bin (defined by the bins in the proton emission angles: $\Delta\theta_1 = \Delta\theta_2 = 2°$, $\Delta\phi_{12} = 10°$ and the bin in energy of 2 MeV).

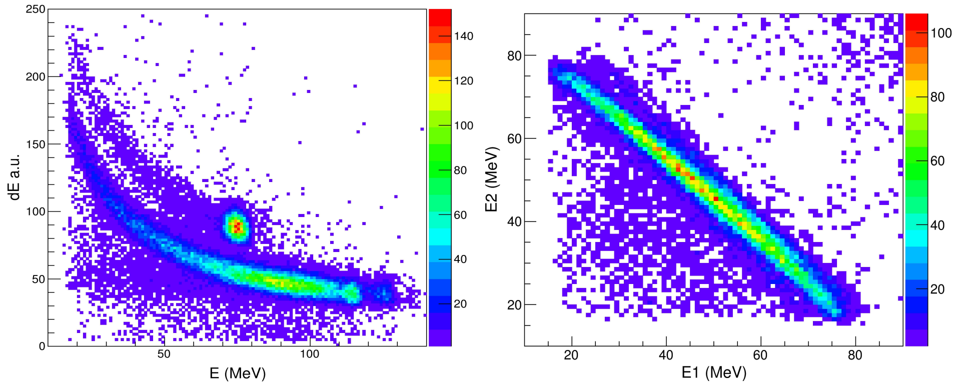

Fig. 1. Left panel: Sample particle identification spectrum measured with one virtual telescope at the beam energy of 135 MeV — a proton band and a deuteron spot are very well-separated. Right panel: Kinematical spectrum measured for a sample configuration of the proton pair ($\theta_1 = \theta_2 = 20°$, $\phi_{12} = 140°$) originating from the breakup reaction; data measured at the beam energy of 108 MeV.

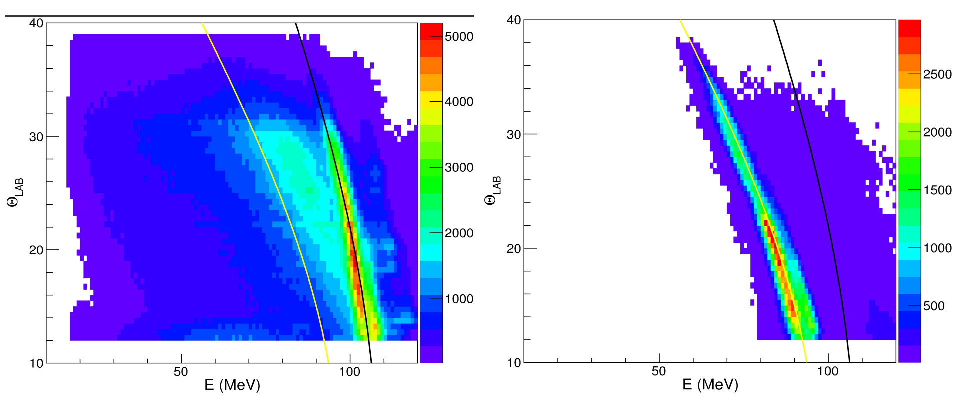

Fig. 2. Particles registered in the Wall presented on the plane of polar angle *versus* energy. The spectra have been produced separately for particles identified as protons (left panel) and deuterons (right panel); the lines represent dependences calculated for elastic scattering kinematics at 108 MeV.

After the PID selection, energy *versus* angle θ dependences have been checked for protons and deuterons separately, see Fig. 2. Bands of elastically scattered protons and deuterons are in agreement with the corresponding kinematical curves.

3. Outlook

The very preliminary analysis of the data taken with the BINA detector at CCB demonstrates a proper and efficient functioning of the forward part of this detector. The aim of the further analysis is to obtain differential cross section of the breakup reaction at 108 MeV as a function of kinematic variables. In a first step, a number of angular configurations of outgoing protons will be chosen. The absolute normalization relies on the elastic scattering data measured in parallel to the breakup reaction and the known elastic scattering cross section [13].

This work was partially supported by the Polish National Science Center (NCN) from grant DEC-2012/05/B/ST2/02556 .

REFERENCES

[1] St. Kistryn, E. Stephan, *J. Phys. G: Nucl. Part. Phys.* **40**, 063101 (2013).

[2] K. Sagara, *Few-Body Syst.* **48**, 59 (2010).

[3] N. Kalantar-Nayestanaki, E. Epelbaum, J.G. Meschendorp, A. Nogga, *Rep. Prog. Phys.* **75**, 016301 (2012).

[4] St. Kistryn *et al.*, *Phys. Rev. C* **68**, 054004 (2003).

[5] St. Kistryn *et al.*, *Phys. Rev. C* **72**, 044006 (2005).

[6] E. Stephan *et al.*, *Phys. Rev. C* **82**, 014003 (2010).

[7] M. Eslami-Kalantari *et al.*, *Mod. Phys. Lett. A* **24**, 839 (2009).

[8] H. Mardanpour *et al.*, *Phys. Lett. B* **687**, 149 (2010).

[9] I. Ciepał *et al.*, *Few-Body Syst.* **56**, 665 (2015).

[10] I. Ciepał *et al.*, *Phys. Rev. C* **85**, 017001 (2012).

[11] St. Kistryn, E. Stephan, *J. Phys. G: Nucl. Part. Phys.* **40**, 063101 (2013).

[12] A. Ramazani-Moghaddam-Arani *et al.*, *Phys. Rev. C* **78**, 014006 (2008).

[13] K. Ermish *et al.*, *Phys. Rev. C* **68**, 051001(R) (2003).